# A COMPUTER PROGRAM FOR BRIDGE RETROFITTING

A. CARNICERO**, R. PERERA*, S. GOMEZ* and E. ALARCON*
** Department of Mechanical Engineering, Pontificia Comillas University (ICAI), Madrid, Spain.
* Department of Structural Mechanics, Technical University of Madrid (UPM), Madrid, Spain.

Abstract
This paper summarizes the work developed in order to establish a framework for seismic retrofitting of bridges. In this context, the first objetive is to find a numerical model to evaluate the damage induced in a structure, under seismic action, as an index of its vulnerability. The model used has the advantage that is based on concepts of fracture mechanics and concentrated plasticity. As a result, the work is based on basic principles. The performance of this model is being evaluated. Some results of the computer program developed for this pourpose are shown.
Keywords: Retrofitting, Vulnerability, Damage.

## 1 Introduction

Bridges are considered in the group of lifeline structures due to the interest of having them working after an earthquake to evacuate people or to receive help from outside of the damaged area. Historical as well as recent earthquakes have shown the vulnerability of existing bridges so it is very important to develop a better understanding of their seismic response both for new designs as well as for the improvement (retrofitting) of existing ones.

As it is well known retrofitting is conducted as a sequence of steps among which it is possible to identify three main groups: First there is a screening of the whole set in order to eliminate of the study those works whose safety can be guaranteed according to current knowledge. Then a simplified study of the remaining items is conducted in which the ductility demands and potentially vulnerable areas are estimated by the use of models with a reduced number of degrees of freedom but with the capability of detecting non-linear effects. Those bridges are ranked according to some 'damage' index and a remedy is designed to retrofit them to eliminate the potential dangers detected. Finally the most dangerous cases are carefully estudied with models of greater complexity and a decission is made to accomodate retrofitting measures.

In Spain, the Directorate of Roads at the Ministry of Public Works has conducted an effort to prepare a program that could be used to retrofit structures complying with the

1995 Spanish new seismic regulations (Norma de Construcción Sismorresistente NCSE-94). The authors have contributed to this effort by developing different computer programs for the two first groups of the retrofitting process.

In this way an expert system was prepared to make possible the screening of a group of bridges selected from the current Ministry computerized Catalog. The lines of reasoning follow substantially the advices of the US and Japan experience according to the seismic hazard, the importance and the vulnerability of the bridge.

In addition some rules where provided to estimate parameters missing in some cases in the bridge Catalog and to interpolate the seismic hazard at the bridge sites.

The process is interactive so that the user has the possibility of selecting the cut- off mark from which more detailed study is needed.

For the step of simplified analysis a first move was to analyze different possibilities of simplified methods, Montans (1994) and Retana (1995), using preselected shapes so that a single degree of freedom system could be used to obtain the significant parameters of the bridge seismic response. Several standard programs (Drain, Ansys, etc. ) were used to get hints at different levels of simplification and finally an apparent interesting solution was found with the so-called 'dynamic hinge method', Montans and Alarcón (1996) and Calvi and Pinto (1996), based on the modification of the bridge characteristics according to the degree of plastification obtained at the knots at different time points.

The study proceeded using artificial as well as historical accelerograms and different degrees of bridge regularity. In all cases, Montans and Alarcón (1996), the procedure performed well even in details of hinge rotations time-histories for very irregular bridges althought in those cases a conservative result was obtained. Those studies were supported by program PREC-8 of the European Commision, Calvi and Pinto (1996).

One of the problems identified at this level was to quantify the seismic damage for those studies. As it is well known Park and Ang (1985) developed an index based on the results of test done over 400 reinforced concrete columns and beams that is currently used to estimate the damage. Both the force and the weakness of that index is the empirical approach to its definition so we have embarked in the quest of a damage index that can be established from first principles. In this sense a very promising approach is the use of Damage mechanics theory for framed structure as proposed by Flores (1995).

This research is currently being conducted under the auspice of project ICONS of the European Commission and their principles are summarized in what follow.

## 2 Basic principes of the model

The model is built based on members composed by an elastic element beam and two plastic-damageable hinges where non-linear efects are concentrated.

Two vetors are defined: A strenght vector,

$$\{M\} = \{M_i, M_j, N\}^t$$

where Mi and Mj are the moments at the ends of the members and N is the axial force, and a displacement vector,

$$\{\phi\} = \{\phi_i, \phi_j, \delta\}^t$$

where $\phi$ collects the rotations of the member at the ends i and j and the span elongation.

Those vectors are equivalent to the stress and strain tensors defined in continuum mechanics. The relationship between loads and displacements can be written as

$$\{M\} = S(d) \cdot \{\{\phi\} - \{\phi^p\}\}$$

where *S(d)* is a stiffness matrix that depends of the damage variable, and $\phi^p$ are the plastic deformations.

The stiffness matrix is formulated using principles of continuum-damage mechanics [Ladeveze, 1983, Mazars 1986]. In this theory, the following law for truss member subjected to axial load is proposed (assuming a constant state of damage in the member)

$$\delta = \frac{A \cdot E}{L \cdot (1-d)} \cdot N = \frac{K_t}{(1-d)} \cdot N$$

where $\delta$ is the strain, A the cross section, E the Young modulus and d the damage parameter.

This expresion is extented to bending as

$$\phi_i = \frac{K_i}{1-d} M_i$$

where $K_i$ is the corresponding term of the stiffness matrix of a beam element.

In this context, the damage index represents a measure of the loss of stiffness of each member.

The existence of a tfermodynamical potential, G, is postulated

$$G = \frac{\partial U^*}{\partial d}$$

where U* is the complementary straing energy. This function, G, is the thermodynamic force asociated to the damage index. This force is therefore equivalent to the energy relase rate introduced in fracture mechanics and carry on the evolution of the damage index.

## 3 Validation of the model

The model presented in the previous paraghaphs has been implimented in a computer program, that will be part of a system for bridges retrofitting.

Currently the model has been calibrated for monotonic and ciclic loads, with and without the possibility of considering plastic deformations.

Some examples of different cases are presented below. The first example shows a frame, simulating a bridge with rigid joints between the piers and the deck, under monotonic load (push-over analysis). The plot ilustrates a force-displacement diagram and the evolution of the damage parameter at the top and botton of the piers. The second example shows a frame under non severe cyclic loads and where, plastic deformation has not been considered. Once again, the plot ilustrates the force-displacement diagram and the evolution of the damage.

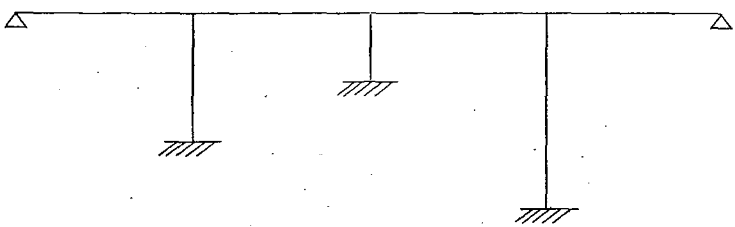

Fig. 1. Model for push-over analysis

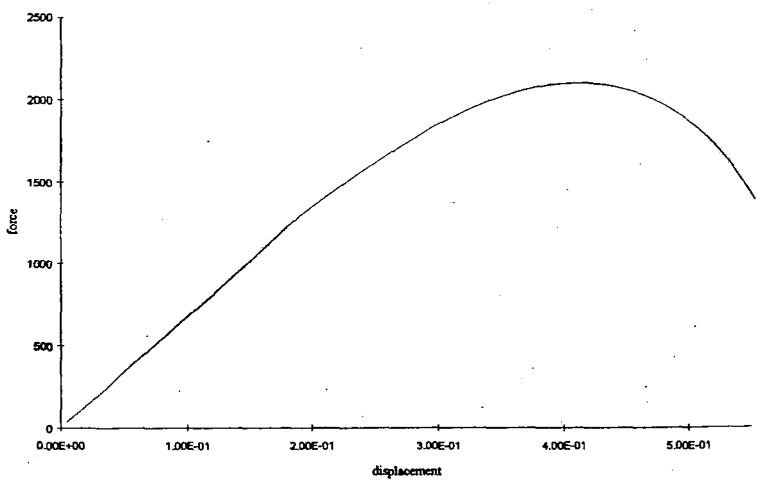


Fig. 2. Force-displacement diagram

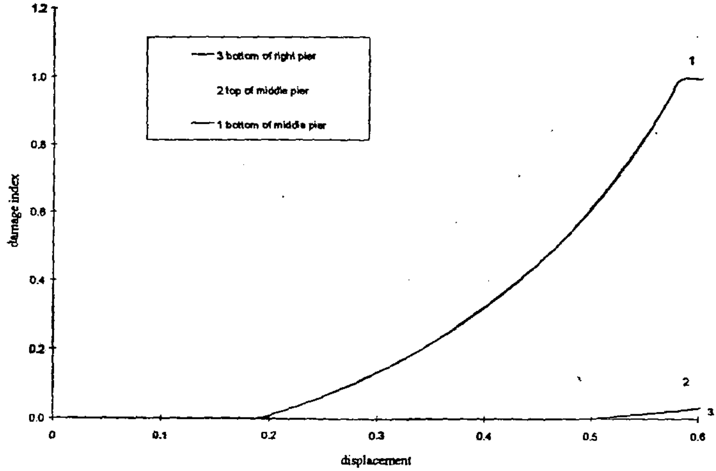


Fig.3. Evolution of the damage index at the hinges

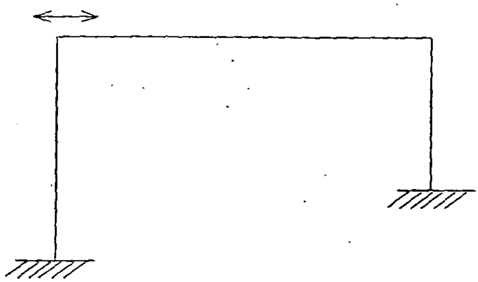

Fig. 4. Model for cyclic analysis

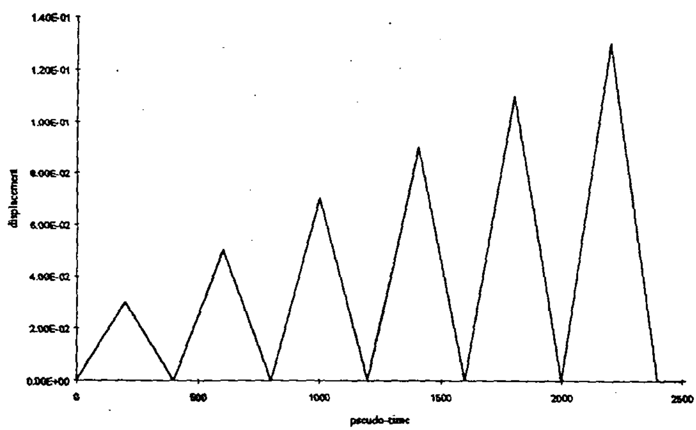


Fig. 5. Displacement history

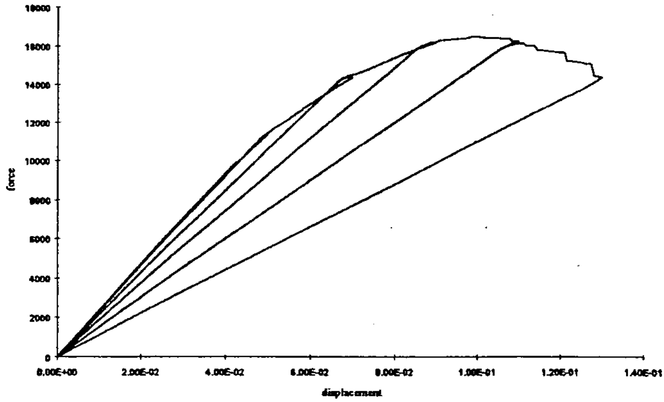

Fig. 6. Force- displacement diagram for cyclic analysis

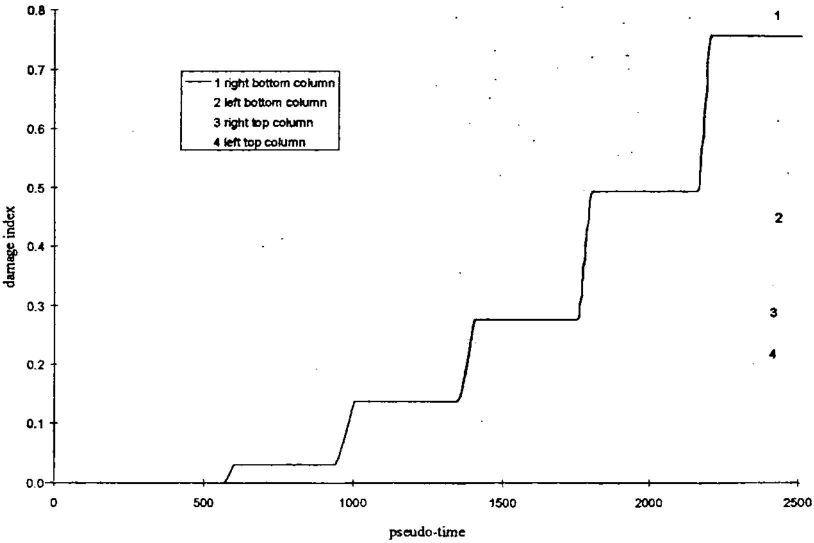


Fig. 7. Evolution of damage index

## 4 Conclusions and future perspectives

The choosed model has the advantages of being based in well known concepts of fracture mechanics, that allow to use it for steel and concrete members. The behavior under cyclic load is based on simple and easily identificable parameters.